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**United States Government Accountability Office**

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PRELIMINARY FACTS AND KEY INFORMATION ON  
GAO'S REVIEW OF SHALE OIL AND GAS RESOURCES  
AND RISKS ASSOCIATED WITH DEVELOPMENT

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## Objectives/Research Questions

Our objectives were to examine what is known about (1) the size of shale oil and gas resources in the United States and the amount produced from 2007 through 2011—the years for which data were available, and (2) the environmental and public health risks associated with development of shale oil and gas.

## Introduction

For decades the United States has relied on imports of oil and natural gas to meet domestic needs. As recently as 2005, it was believed that in the future, the nation would rely on even greater imports of natural gas to meet its growing demand. However, in recent years, improvements in technology have allowed companies that develop petroleum resources to extract oil and natural gas from shale formations<sup>1</sup> that were previously considered inaccessible because traditional techniques did not yield sufficient amounts for economically viable production. In particular, new applications of horizontal drilling and hydraulic fracturing—in which water, sand, and chemical additives are injected under high pressure into shale formations to create fractures in underground formations and allow oil and natural gas to flow—allow significant amounts of natural oil and gas from shale formations, known as “shale gas” and “shale oil”, to be developed from these low-permeability formations, thus transforming the nation’s energy portfolio.

As exploration and development of shale oil and gas have increased—including in areas of the country without a legacy of oil and natural gas activities—questions have been raised regarding the estimates of the size of these resources as well as the processes used to extract them.<sup>2</sup> Some nongovernmental organizations have questioned the estimates of the shale oil and gas supply prepared by the federal government and other groups. In particular, some of these organizations have expressed concerns that estimates may be inflated, which, in turn, could discourage interest in production of renewable energy sources. In addition, questions about the

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<sup>1</sup>In our discussion of shale oil and gas, we are not referring to “oil shale.” Oil shale requires a different process to extract and develop. Specifically, to extract the oil from oil shale, the rock needs to be heated to very high temperatures—ranging from about 650 to 1,000 degrees Fahrenheit—in a process known as retorting. For additional information on oil shale, see GAO-11-35.

<sup>2</sup>For the purposes of this report, resource refers to concentrations of naturally occurring hydrocarbons and can be divided into undiscovered resources and reserves.

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environmental and public health effects of the increased use of horizontal drilling and hydraulic fracturing, particularly on water resources and air quality, have garnered extensive public attention. These concerns have led some communities and certain states to impose restrictions or moratoriums on drilling operations in order to have time to study and better understand the potential risks associated with these practices.

## Background

Oil and natural gas are found in a variety of geologic formations. Conventional oil and natural gas can be found in deep, porous rock or reservoirs that can flow under natural pressure to the surface after drilling. In contrast to the free-flowing resources found in conventional formations, the low permeability of some formations, including shale, means that oil and gas trapped in the formation cannot move easily within the rock, and it is typically necessary to stimulate the rock (usually through the injection of fluids under high pressure) to create fractures, and additional permeability, thus allowing gas or oil to be extracted. Other formations, such as coal beds and tight sands, may also require stimulation to allow gas or oil to be extracted. Although there is no clear and consistently agreed upon distinction between conventional and unconventional oil and gas, unconventional sources generally require more complex and expensive technologies for production, such as hydraulic fracturing.

Most of the energy used in the United States comes from fossil fuels such as oil and natural gas. The primary uses of natural gas are to heat buildings, power the industrial sector, and generate electricity. Natural gas provides about 25 percent of the energy used in the United States, supplying nearly half of all the energy used for cooking, heating, and powering other home appliances, and generating almost one-quarter of U.S. electricity supplies. Oil supplies about 40 percent of all the energy the country consumes and almost the entire U.S. transportation fleet—cars, trucks, trains, and airplanes—depend on fuels made from oil. .

### The Shale Oil and gas Development Process

The process to develop shale oil and gas is similar to the process for conventional onshore oil and gas, but shale formations rely on the use of horizontal drilling and hydraulic fracturing—which may or may not be used on conventional wells. Horizontal drilling and hydraulic fracturing are not new, but technological advancements and refinements have greatly expanded operator's

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abilities to use these processes to economically develop shale oil and gas resources.

Once operators have negotiated contracts or leases that allow mineral development, identified a location for drilling, and obtained necessary permits, they undergo a sequence of events to develop shale oil and gas. While the specific activities and steps taken to extract shale oil and gas vary based on characteristics of the formation, the development phase generally involves the following stages: (1) well pad preparation and construction, (2) horizontal drilling and well construction, and (3) hydraulic fracturing and flowback.

## Well Pad Preparation and Construction

The first step is to prepare and construct the well pad site. Typically, four to six acres of surface must be cleared of vegetation and leveled to make room for numerous vehicles, large equipment—such as generators—and other infrastructure. Then, operators must transport necessary equipment, including tanks, pumps, blender pumps—equipment used to mix additives, water, and sand needed for hydraulic fracturing—water and sand storage tanks, monitoring equipment, and additive storage containers. Based on the geological characteristics of the formation and climatic conditions, operators may (1) excavate a pit to store freshwater, drilling fluids, or drill cuttings—rock cuttings generated during drilling, (2) use tanks to store materials, or (3) build temporary transfer pipes to transport materials from an off-site location.

## Horizontal Drilling and Well Construction

The first step to construct a well is drilling. Operators use a drilling rig to drill a hole (referred to as the wellbore) thousands of feet into the earth through a combination of vertical and horizontal drilling techniques. At several points in the drilling process—such as the point at which drilling reaches the bottom of the aquifer—the drilling rig is removed from the wellbore to insert casing and cement.<sup>3</sup>

Drilling mud, also known as drilling fluid, is a lubricant that is pumped through the wellbore at

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<sup>3</sup>Casing is a metal pipe that is inserted inside the wellbore to prevent high-pressure fluids outside the formation from entering the well, and to prevent drilling mud inside the well from fracturing fragile sections of the wellbore. As drilling progresses with depth, casings that are slightly narrower than the hole created by the drill bit are inserted into the wellbore and bonded in place with cement, sealing the wellbore from the surrounding formation.

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different densities to balance the pressure inside the wellbore and bring rock and other matter cut from the formation back to the rig. A blowout preventer is installed over the well to control and divert any high-pressure gas that may be encountered while drilling. Drill cuttings are brought to the surface. Mud pits excavated adjacent to the drill rig provide a reservoir for mixing and holding the mud. The mud pits also serve as settling ponds for the cuttings. At the completion of drilling, the mud may be recycled for use at another drilling operation.

Instruments guide drillers to the “kickoff point”—the point at which drilling starts to turn at a slight angle, usually by about 12 degrees, so that the well turns as it nears the shale formation and extends horizontally. Production casing and cementing are then inserted to extend the length of the borehole. After drilling to the target depth, the drilling operator may run a cement evaluation log by lowering an electric probe into the well to measure the thickness of the cement. The purpose of the cement evaluation log is to confirm that the cement will function as designed—preventing well fluids from migrating outside the casing and infiltrating overlying formations.

Throughout the drilling process, operators typically vent or flare some natural gas, often intermittently in response to maintenance needs or equipment failures. This intermittent venting may take place when operators purge water or other liquids that collect in well bores to maintain proper well function.

## Hydraulic Fracturing and Flowback

Following construction of the well, operators stimulate the shale formation through hydraulic fracturing. Before operators or service companies perform a hydraulic fracture treatment of a

well, a series of tests may be conducted to ensure that the well, well-head equipment, and

fracturing equipment can safely withstand the high pressures associated with the fracturing process. Minimum requirements for pressure testing are typically determined by state regulatory agencies.

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To hydraulically fracture a well, a perforating gun is inserted into the casing. An electrical charge is sent by wire to detonate a charge in the perforating gun, which blasts small holes through the casing and cement into the shale. Hydraulic fracturing fluid is then injected into the well at high pressure. Figure 4 provides greater detail about fracturing fluid. About 99 percent of hydraulic fracturing fluid is water and resin coated sand or ceramic beads (proppant) and about one percent of hydraulic fracturing fluid is a mix of various chemicals. Fracturing fluids are tailored based on the shale thickness, local stress conditions, compressibility, and rigidity. Local

conditions are used in computer models to design site-specific hydraulic fluids. The water,

chemicals, and proppant used in fracturing fluid are typically stored on site in separate tanks and blended just before injection into the well.

Pressure forces the fracturing fluid through the perforations in the pipe and into the surrounding formation—which can be shale, coal bed methane, or tight sand—expanding existing fractures and creating new ones in the process. After the fractures are created, the pressure is reduced. The proppant stays in the formation to hold open the fractures and allow the release of oil and gas. Some of the fracturing fluid that was injected into the well will return to the surface (known as the flowback process) along with water naturally found in the formation—so-called produced water. The fracturing fluid as well as any produced water is brought to the surface and collected by the operator. The collected water is typically collected by tank trucks and hauled offsite to underground injection disposal wells, wastewater treatment plants, or treatment and reuse facilities. Given the length of horizontal wells, hydraulic fracturing is often conducted in stages, where each stage focuses on a limited linear section and may be repeated numerous times.

Once the well is producing natural gas or oil, most of the equipment and temporary infrastructure is no longer needed and will be removed, leaving only the parts of the infrastructure required to collect and process the gas and ongoing produced water. Operators begin to reclaim the part of the site that will not be used. Throughout the producing life of a gas or oil well, the operator may find it necessary to periodically re-stimulate the flow of oil and gas by repeating the hydraulic fracturing process. The frequency of such activity depends on the

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characteristics of the geologic formation, and the economics of the individual well. If the hydraulic fracturing phase is repeated, the site and surrounding area will be further impacted by the required infrastructure, truck transport and other activity associated with this process.

## Regulatory Framework

Shale oil and gas development, like conventional onshore oil and gas production, are regulated through a framework of laws and regulations at almost all levels of government, but most regulatory authority lies with the states. With few exceptions, all of the laws, regulations, and permits that apply to conventional oil and gas exploration and production activities also apply to shale gas development.

- **Federal.** A number of federal agencies administer laws and regulations that apply to various phases of shale oil and gas development. For example, BLM manages and regulates federal lands and the mineral resources underneath. EPA administers and enforces key federal laws to protect human health and the environment, and EPA regional offices work with states, which implement some aspects of these laws as well as requirements the state may also impose. Other federal land management agencies, including the U.S. Department of Agriculture's Forest Service, the Department of Interior's National Park Service, and Interior's Fish and Wildlife Service manage federal lands, including shale oil and gas development on federal lands.
- **State.** States have primary regulatory responsibility for shale oil and gas development. State agencies administer many federal environmental regulations and implement additional state regulations covering nearly every phase of oil and gas operations. The degree of local regulation, such as by municipalities, may also be subject to state control.
- **Other.** Additional requirements regarding oil and gas operations may be imposed by various levels of government for specific locations. Entities such as cities, counties, tribes, and regional water authorities may set additional requirements that affect the location and operation of wells.

## Location of Shale Plays

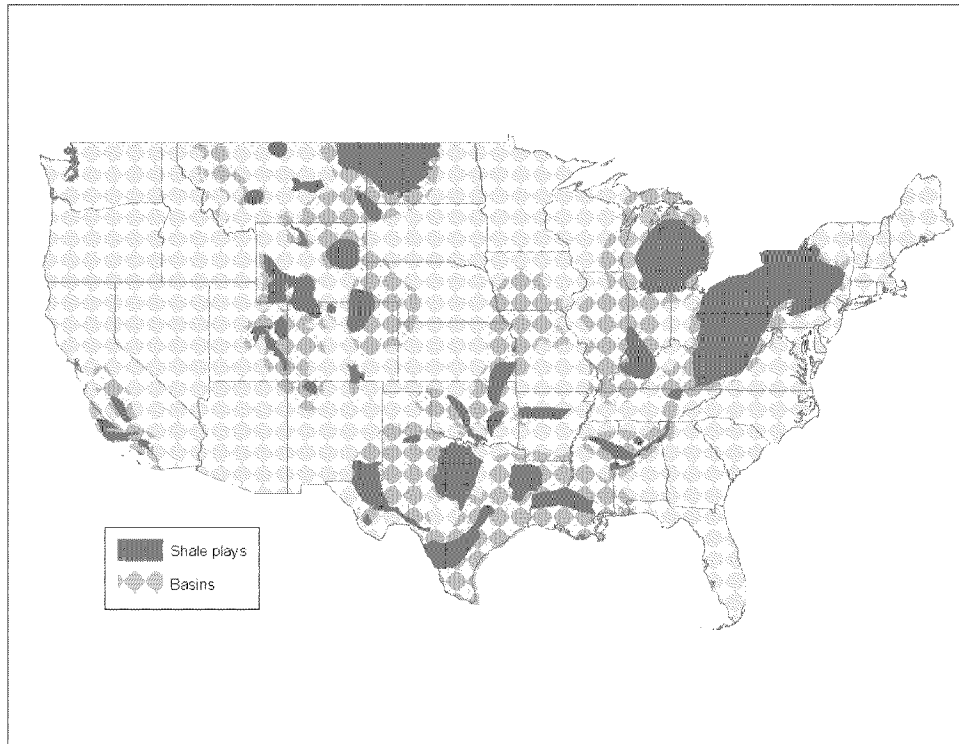
Shale oil and gas are found in shale plays—a set of discovered or undiscovered oil and natural



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gas accumulations or prospects that exhibit nearly identical geological characteristics—on private, state-owned lands and federal lands across the United States. There are at least 21 shale plays in 25 states.

Figure 5: Shale plays and basins in the lower 48 states



Source: Energy Information Administration (shale location data) and MapInfo (map).

A shale play can be developed for natural gas, oil, or both. In addition, a shale gas play may contain “dry” or “wet” natural gas. Dry natural gas is a mixture of hydrocarbon compounds that exists as a gas both underground in the reservoir and during production under standard temperature and pressure conditions. Wet natural gas (natural gas liquids) is the portion of the hydrocarbon resource that exists as a gas when in natural underground reservoir conditions, but is liquid at surface conditions. The natural gas liquids are typically propane, butane, and ethane, and are separated from the produced gas and liquefied at the surface in lease separators, field facilities or gas processing plants. Operators may then sell the natural gas liquids, which may give wet shale gas plays an economic advantage over dry gas.

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## Estimating the Size of Shale Oil and Gas Resources

Estimating the size of shale oil and gas resources serves a variety of needs for consumers, policy makers, land and resource managers, investors, regulators, industry planners, and others. For example, federal and state governments may use resource estimates to estimate future revenues to the government, and establish energy, fiscal, and national security policies. The petroleum industry and the financial community use resource estimates to establish corporate strategies and make investment decisions.

A clear understanding of some common terms used to describe the size and scope of natural oil and gas resources is needed to determine the relevance of a given estimate. The most inclusive term is in-place resource. The in-place resource represents all natural gas or oil contained in a formation without regard to technical or economic recoverability. In-place resource estimates are sometimes very large numbers, but only a small proportion of the total amount of natural gas or oil in a formation is ever recovered.

Technically recoverable resources are a subset of in-place resources that include only gas or oil that is producible given available technology. Technically recoverable resources include those that are economically producible and those that are not. Estimates of technically recoverable resources are dynamic, changing to reflect the potential of technology, costs, prices, and regulations.

Proved reserve estimates are more precise than technically recoverable resources and represent the amount of oil and gas that have been discovered and defined, typically by drilling wells or other exploratory measures, and which can be economically recovered within a relatively short timeframe. Proved reserves may be thought of as the “inventory” that operators hold and defines the quantity of oil and gas that an operator estimates can be recovered under current economic conditions, operating methods, and government regulations. Estimates of proved reserves increase as new discoveries are made and decline as oil and gas reserves are produced and sold. In addition, reserves can change as price and technology change. For example, technology improvements that enable operators to extract more gas or oil from

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existing fields can increase proved reserves. Likewise, increased market prices for oil and gas reduce the relative costs of development, also increasing proved reserves. On the other hand, price decreases diminish the amount of resources likely to be produced, reducing proved reserves. Historical production is the most precise information available as it represents actual production amounts.

## Objective 1: Size and Production

**Not applicable for EPA exit meeting**

## Objective 2: Information on Potential Environmental and Public Health Risks

The studies and publications we reviewed and the stakeholders with whom we spoke identified various potential risks to water and land resources, air quality, and human health from shale oil and gas development. In general, each identified risk is associated with one of the three stages of shale oil and gas development—well pad preparation and construction, horizontal drilling and wellbore construction, or hydraulic fracturing and flowback.

### Well Pad Preparation and Construction

The studies and publications we reviewed and stakeholders with whom we spoke identified a number of potential environmental and human health risks associated with well pad preparation and construction, including habitat degradation, water and soil contamination, and air pollution.

### Horizontal Drilling and Well Construction

The studies and publications we reviewed and stakeholders with whom we spoke identified a number of potential environmental and public health risks associated with horizontal drilling and well construction, including water contamination, air pollution, exposure to normally occurring radioactive materials (NORM), and disturbances to quality of life.

According to a study we reviewed, air emissions have become a significant concern associated with shale gas development, including the contribution of shale gas activities to ozone levels.

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While the study concludes that shale gas development activities contribute ozone precursors (such as volatile organic compounds and nitrous oxides) into the atmosphere, several stakeholders told us that EPA and the industry disagree on the amount of emissions released.

Volatile organic compounds, present in vented gas, contribute to elevated ozone and haze, and ozone is a known carcinogen, according to EPA.

According to EPA, in many western states, including in many rural areas where there is substantial oil and gas production and little population, there have been increases in ozone levels, often exceeding federal air quality limits.

Natural GasSTAR Program (*shown as a side bar in the report*)

The EPA initiated the Natural Gas STAR program, a nationwide, voluntary effort aimed at reducing methane emissions from the oil and gas industry. EPA's program has encouraged some operators to adopt technologies and practices that have helped to reduce methane emissions from the venting of natural gas, according to EPA and industry participants. Through this program, industry partners evaluate their emissions and consider ways to reduce them, although the reductions are voluntary. The program also maintains an online library of technologies and practices to reduce emissions that quantify the costs and benefits of each emission-reduction option. Natural GasSTAR also sponsors conferences to facilitate information exchange between operators regarding emissions reductions technologies. Partner companies report annually about their efforts to reduce emissions along with the volumes of the emission reductions.

Hydraulic Fracturing and Flowback

The studies and publications we reviewed and stakeholders with whom we spoke identified a number of potential environmental risks associated with hydraulic fracturing and flowback activities, including water contamination, water shortages, and air pollution.

The studies and publications we reviewed did not identify any instances of groundwater

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contamination as a result of fractures created during shale oil and gas development, but there are a number of ongoing reviews on the subject. For example, EPA's Office of Research and Development initiated a study in January 2010 to examine the potential effects of hydraulic fracturing on drinking water resources. The study plan is currently being reviewed by EPA's Science Advisory Board, and the agency anticipates issuing an interim report in the fall of 2012 and a final report in 2014.

EPA is conducting a study to evaluate information on the relationship between underground injection wells and seismic events. The report is scheduled to be publicly released in the summer of 2012.

## EPA's Groundwater Investigation in Pavillion, Wyoming

In response to complaints regarding objectionable taste and odor in well water, near the town of Pavillion, Wyoming, the EPA initiated an investigation to determine the presence of groundwater contamination above the Pavillion gas field, and to the extent possible identify the source of the contamination. The Pavillion gas field is a tight sand formation made up of sandstone. Natural gas is extracted from the formation through 169 production wells. Geological differences between sandstone and shale are important to note because sandstone, in contrast to shale, has enough permeability to transmit groundwater to water wells in the region. In a sense, the sandstone acts as a reservoir for both natural gas and for groundwater. Shale formations, such as the Marcellus Shale, are not permeable enough to transmit water and generally not considered aquifers. On December 14, 2011, EPA released a draft report outlining findings from the investigation. Although the report is not finalized and currently undergoing peer-review, the agency indicated that it had identified certain constituents in groundwater above the production zone of the Pavillion natural gas wells that are consistent with some of the constituents used in natural gas well operations, including the process of hydraulic fracturing. However, EPA states that further investigation is needed to determine potential migration pathways. According to a January 2011 report by the Congressional Research Service, regardless of these outcomes, the potential applicability of EPA's findings at the Pavillion site to other sites where similar hydraulic fracturing operations are conducted would depend heavily upon the extent to which the geology and hydrogeology are similar, as well as other location-specific factors.

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The studies and other publications we reviewed and stakeholders we spoke with also identified potential health risks as an area of concern for shale oil and gas development, primarily focused on the use of toxic chemicals in all phases. However, researchers disagree about the potential harm to public health from use of toxic chemicals, as long as operators properly manage the fluids.

The potential environmental and public health risks identified in the studies and publications we reviewed may not apply to all shale basins because of location-specific factors, including: geological characteristics—such as permeability, thickness, and porosity—and climatic conditions. In addition, the location specific factors can affect the ability to extrapolate research results from one location to another.

A number of studies we reviewed indicate that the potential environmental and public health risks are primarily due to management or equipment failures, not technological shortcomings. As such, the extent to which operators follow and properly implement available technologies and best practices can significantly affect the environmental and public health risks at a development site.